Journal of Cleaner Production 258 (2020) 120951

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Date palm trees supply chain and sustainable model

Ahmed Abu Hanieh [a, *], Afif Hasan [a], Muhammed Assi [b]

[a] Mechanical & Mechatronics Engineering Department, Birzeit University, Palestine
[b] Master Program Sustainability Engineering, Birzeit University, Palestine

ARTICLE INFO

Article history:
Received 7 November 2019
Received in revised form
29 February 2020
Accepted 5 March 2020
Available online 6 March 2020

Handling Editor: Mingzhou Jin

Keywords:
Date palm
Sustainability
Lifecycle
Supply chain
Feasibility
Added value

ABSTRACT

Cultivation and sustainability of Date palm in Palestine is the main focus of this paper. Lifecycle and food supply chain are represented using integrated definition block diagram showing the inputs and outputs of date palm tree cultivation. Doughnut model is used to represent the sustainability of the date palm tree, such modeling technique leads to practical solutions for the enhancement of the different pillars affecting sustainability. The added value and accumulated added value techniques are used to examine the feasibility of date palm growing and cultivation. Based on accumulated added value the payback period for a palm tree is 12 years and the lifetime of a palm tree is 41 years. The lifetime added value per palm tree can reach up to USD 5360 indicating a yearly profit of USD 208 per one tree during the peak period from 10 to 35 years of its age. The feasibility of the sector could be improved by increasing the added value in parallel with ensuring sustainability of the sector.

1. Introduction

1.1. Background

The total number of palm trees planted in the thirty countries that are date producers reaches 120 million trees; the fruit production of these trees is about 7.5 million tons (FAO, 2013). Arab countries' share in the global date production is estimated as 67% (El-Juhany, 2010).

In the West Bank of Palestine Jericho and the Jordan Valley have 600 ha (ha) of date palm trees, with production capacity of 5000 metric tons in 2015, and Medjoul is the major cultivar. Gaza strip alone has produced 1300 metric tons of dates in 2015 with Hayani as a major cultivar. Table 1 shows the major date cultivars, planted area (in donums where 10 donums = 1 ha), and number of trees in Palestine. Fig. 1 shows the growth of the Palm trees cultivation areas in the West Bank. According to (FAO, 2013) the contribution of date palm products in the total value of the agricultural output is 3%. The average date consumption of the Palestinian person is 0.9–1.8 kg per year.

The best climate for date cultivation is the hot and dry climate, knowing that date palms can grow in alkaline and salty soil. Thus, sand can be a good environment for them where their roots can go deep to one or 2 m. Palms can grow in temperatures from 13 to 28 °C, however it can tolerate hot summer with temperature up to 50 °C. Shortage of rain that makes a low humidity environment can benefit palm trees in the pollination to harvest period. Nevertheless, palm trees can withstand short periods of frost down to a temperature of −5 °C. Whereas, the best temperature range for them is from 21 to 27 °C (Proposal UAE, 2015). Climate conditions in Jordan Valley and Gaza Strip as shown in Table 2 are suitable for date's production.

1.2. Problems and obstacles

New cultivars such as Medjoul, Barhi, and Deglet Nour proved to grow well under Jordan Valley climate conditions and hence is replacing the old Baladi cultivar. Whereas, in Gaza, 90% of the cultivars are still Hayani and the rest are other varieties. The pests and diseases infecting date palms are the main reasons for losses of palm date farmers (Abed Rabou and Radwan, 2018).

The development and improvement of date palm production in Palestine is restricted by different obstacles. Undeveloped marketing structure, the high cost of investment, and the high competition with foreign products are considered the main obstacles. Diseases, water

* Corresponding author.
E-mail addresses: ahanieh@birzeit.edu (A.A. Hanieh), ahasan@birzeit.edu (A. Hasan), enkarem2006@gmail.com (M. Assi).

https://doi.org/10.1016/j.jclepro.2020.120951
0959-6526/

Table 1
Major date cultivars, areas, and productivity in West Bank and Gaza Strip.

	Cultivar	Fruit date area (donum)	Number of Palm trees
West Bank	Medjool	11,172	217,100
	Barhi	213	2820
	Baladi	169	2500
	Deglet Nour	16	210
	Total	11,570	222,630
Gaza Strip	Hayani		210,000
	Bent-aisha		25,000
	Barhee		10,000
	Other cultivars		5000
	Total		250,000

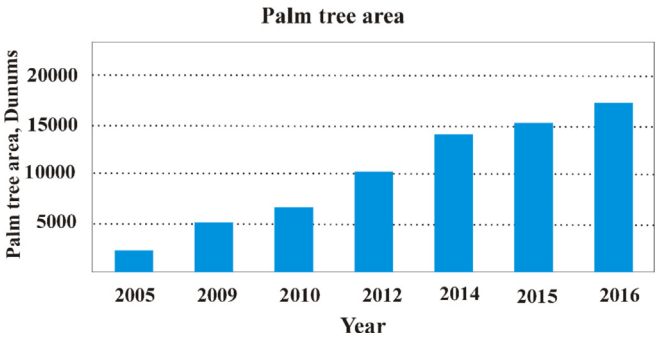

Fig. 1. Growth of palm tree cultivation area in West Bank.

Table 2
Average temperature and relative humidity requirements for date cultivation and ripening in Jericho and Gaza Strip (UNEP, 2003).

Location	Average temperature °C		Relative humidity %	
	summer	winter	summer	winter
Jordan valley	24–39	8–18	51	73
Gaza Strip	24–39	10–15	86	89

shortage and Lack of rejuvenation programs are hindering the productivity and profitability improvement.

The entry of Palestinian Medjoul to the European market is still not fully developed. Efforts should be made to increase the growing capacity and meet the standard requirements for competition with other high quality Medjoul exporting countries such as Morocco, United States (California, Arizona), Namibia, South Africa and Israel.

Date palm tree is one of the oldest trees in the Middle East and in Palestine particularly, nevertheless, this crop was not one of the main agricultural income crops for a long time. Recently, investors started to look at the sector as a profitable source of income, which leads to the expectations that palm dates will be a main competitor for olives in the Palestinian agricultural sector.

Due to the expectations that the date palm sector will be accounted as a national and strategic crop in Palestine, this study investigates the various aspects of date palm cultivation in Palestine. The study is an attempt of building sustainability model for the dates production and palm tree cultivation in Palestine. In order to strengthen palm sector development it is required to maximize productivity, profit, and employment while using efficiently the land and water resources.

1.3. Literature review

Literature concerning the sustainability of Date Palm tree is very limited, however a lot of work and literature is related to the specific topic of palm oil and palm oil industry. Such as the one by Forum for sustainable palm oil (Forum, 2019; Nulken et al., 2015), it explains the size and intensity of the problem with oil palm plantations covering seventeen million hectares of the Earth's surface. This area is planned to be expanded where Indonesia is planning to widen the area cultivated by oil palm trees to twenty million hectares by 2025. This expansion is accompanied by greenhouse gases emission and removal of rainforests to plant the oil palms. On the social and political level, conflicts will start between the local people and the big companies on land ownership and usage and personal human rights of the workers.

The palm oil industry involves stakeholders from seven sectors; banks, manufacturers, traders, oil producers, retailers, processors and non-governmental organizations (NGOs). These stakeholders made together a Roundtable on Sustainable Palm Oil (RSPO) platform to conform an international understanding that can be translated into actions to be taken in order to develop and implement standards to obtain sustainability for the palm oil production. These environmental and social actions make a criteria for the producing companies to follow and implement for the production of certified sustainable Palm oil (CSPO) which leads to reduce the environmental and social impact of palm oil production on environment and communities (RSPO, 2019).

Sustainability of reuse and recycle processes of the different components of date palms was addressed by several researchers (Al Bulushi et al., 2018). discusses an optimization tchnique to extract the CO_2 from the palm leaves waste which shows one of the recycling processes discussed from economic point of view. Recycling of date pits is tackled by the authors of (Guesmi et al., 2016) who discussed their project based on the fabrication of multifibers out of date pits powder. Silitonga and his co-authors from Malaysia present the possibility of producing biodiesel from palms, the authors discuss the chemical and physical properties of this biodiesel in this reference (Silitonga et al., 2016). Date palm tree cultivation in Afar Regional State of Ethiopia is discussed in (Lemlem et al., 2018). This article tackles the evaluation of best practices and obstacles facing date palm production along the value chain. Date palm trees are irrigated using traditional flooding irrigation and suffers from the impact of diseases and insects that influence the product. For the purpose of production improvement, this research paper proposes making capacity building and management techniques for the pre-harvest and post-harvest processes of date palm cultivation.

Some publications tackled the date palm cultivation from the industrial point of view taking into account the chemical and physical properties of the palm tree and the dates and their influence on the different industrial processes. Pyrolysis and combustion kinetics of date palm biomass was studied in (Sait et al., 2012) who used thermogravimetric analysis to study the physical properties of date palm biomass. University of Putra in Malaysia in (Al-Oqla and Sapuan, 2014) studied the feasibility of using date palm trees to manufacture natural fiber composites that can be used in automotive industry. The chemical composition of date palm was studied by King Saud University in Saudi Arabia (Fayyadh and Al-Showiman, 1990) where the qualitative analysis showed that it contains important substances like fatty acids, sugars, minerals, vitamins, enzymes and other significant organic components.

The International Center for Agricultural Research in the Dry Areas (ICARDA) led a research project which is funded by the Gulf Cooperation Council (GCC) aims to improve date palm crop management, as well as create and transfer best-practice technologies (Mesut Keser, 2017). ICARDA worked to improve production methods through the following measures;

- Implementing and expanding liquid pollination method. Spraying palm trees with a pollen solution. They found that production costs decreased significantly, hence the value of production per hectare increased by almost 50% in some cases.
- Introducing subsurface irrigation, for a well-implemented system water loss and run-off are reduced. They found that the precise and uniform delivery of water improved crop yield.
- ICARDA Promoted Integrated Pest Management (IPM) as an alternative to chemical pesticides in order to reduce damage to the local environment and human. This involves the use of biopesticides and other more natural options.

Published research and experience in date cultivation in other countries show a room for improving sustainability of the date palm cultivation in Palestine. Production and revenues could be increased meanwhile water resources can be conserved, and health and safety of workers can be maintained.

2. Lifecycle and supply chain of date palms

Due to the picularity of the date tree, specific cultivation processes to be undertaken on specific dates during its life time. Such processes include pollination, bunch managment, fruit thinning, harvesting, and pruning all these require reaching the crown of the tree which can be at tens of meters in height. Such cultivation processes require specific tools and skills, and will impose challenging and dangerous situations for the workers.

Date Palm tree supply chain can be summarized as follows: planting, cultivation, harvesting fruits, treatment, packaging, product transport, and consumption. Date Palm product could be consumed in different forms and go through different manufacturing processes depending on the desired product for consumption. Six inputs have to be taken into consideration in order to grow a palm tree; irrigation, energy, machinery, labor, fertilizers and pesticides (Abu Qaoud, 2015). Such inputs are shown for each process in Table 3. The table shows also main required inputs and expected outputs for each process. These processes are explained breiflly below in this section.

Figs. 2 and 3 present flow charts of the above date palm processes with the inputs (resources) and output products and wastes.

A palm tree needs to be irrigated by 100–140 m^3 of water every year, this high quantity of water makes a great challenge for the farmers knowing that Palestine suffers from a deep shortage of water specially in the Jordan Valley and Gaza where most of the palm trees grow. Farmers try to collect rain water during winter in basins near their farms to be used for irrigation in summer besides to using efficient irrigation techniques like drip irrigation. Energy is another main input for the cultivation of palm trees, it is required for irrigation water pumping, as well as for trimming and harvesting season.

Hand working labor is used widely in date palm cultivation

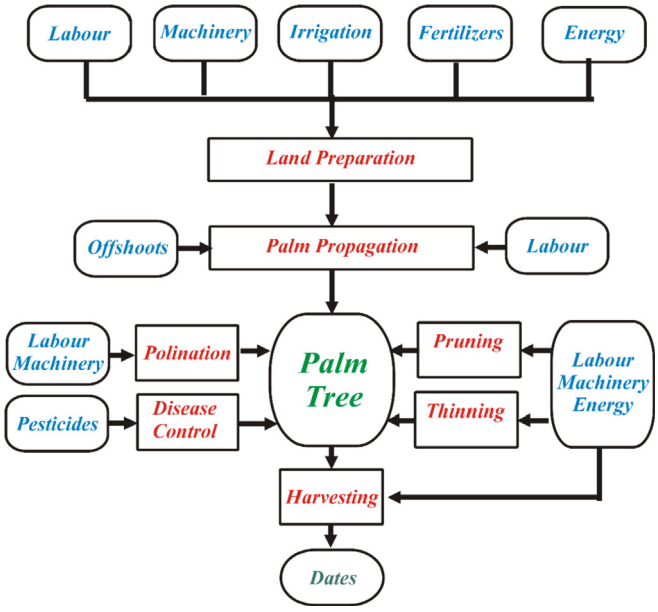

Fig. 2. Different Pre-harvesting processes of cultivation for the date palm tree.

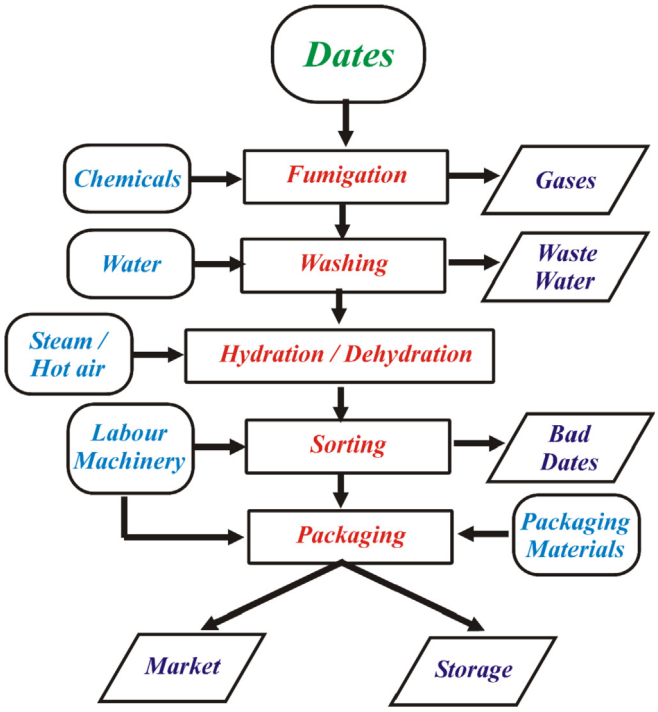

Fig. 3. Post-harvesting processes for date production.

Table 3
Date palm inputs and outputs for cultivation processes.

Process	Inputs	Outputs
Date palm propagation	Labor, offshoots	Offshoots
Land preparation& planting operation	Labor, tools & machinery, fertilizers, water, ploughing	Planting new tree
Date palm irrigation	Irrigation system, labor, water, energy	Tree grow
Pollination	Pollen, labor, machinery & tools	Pollinated trees
Bunch management	Labor, tools & machinery	Fronds, accidents and injury, well managed tree.
Disease & insects control	Pesticides, labor, tools & machines	Healthy tree & fruits, air & soil pollution, labor accidents & sickness
Fruit thinning	Labor, tools & machinery	Well distributed fruit, injury, and waste fruit.
Date harvesting	Labor, tools & machinery	Date Fruits
Treatment-sorting-packaging	Machinery, water, chemicals, labor	Healthy unspoiled packaged dates, wastewater, bad fruits, chemicals waste

because most of the processes need basic farming skills, although higher skills can be gained by establishing training programs for them. In spite of the existence of hand working farmers, there is a high need for machinery and special equipment for cultivation and harvest. Fertilizers are one of the important inputs to the process to make sure of feeding trees with the necessary elements for better production.

Red palm weevil is one of the most dangerous pests (insects) that damage palm trees. Resisting these pests need the use of pesticides.

2.1. Date palm propagation

Offshoots from the parent tree are used to grow new trees, hence will ensure identical trees and fruits to their parents. Six to eight years are needed before the pups can be transplanted to the land to form the a new tree, another six or seven years will elapse before they are able to produce fruits. Other propagation techniques involve seed propogation and tissue culture.

2.2. Land preparation

Sandy soils are mostly used for date plantations, the date palm has a high tolerance for salty soils.

The aim of land preparation is to make soil conditions suitable for a successful planting of the young offshoots transferred from the nursery. At this stage the field is prepared by installing irrigation system, digging holes, soil improvement such as application of organic matter; and reduction of soil salinity.

2.3. Planting operation & fertilization

When planting the offshoot the plant's bulb should be at the same level of the soil surface and the irrigation water must not cover the top of the plant. Once the new pups are planted, "flat top" haircut is done to them, their heart is protected by wrapping them in cardboard or similar manner. A soil basin is made around the palm pup to ensure a suitable water supply for the plant.

It is important after transplanting the bulbs to provide in the required nutrient for the young offshoots. Such nutrients include calcium, boron, chlorine, cobalt, iron, copper, magnesium, molybdenum, manganese, nitrogen, potassium, phosphorus, sulphur, sodium, and zinc, in sufficeint rates.

2.4. Date palm irrigation

Flood irrigation method is the oldest and at relatively low cost, however with low efficiency, intensive labor and un-suitable for sandy soil. It consumes a big quantity of water and exposed to evaporation. Basin irrigation has low initial cost, low running cost, easy to apply, while disadvantages include intensive labor and obstruction of mechanical operations.

In sprinkler irrigation less labor is required and efficient use of water; while the disadvantages include high initial cost, high running costs, could be affected by wind and temperature, and not well suited for small palms as water can enter from above into the heart of the palm.

Drip irrigation is the most efficient use of water, low running costs, is not affected by wind, could be automated; hence less labour is needed. Disadvantages include high initial cost, and requiring very clean water (Abdelouahhab, 2002).

2.5. Pollination

Birds and bees do not contribute in pollinating date palm trees because they are neither attracted to the female flowers nor to the male pollens, hence hand pollination of the females have to be employed since it cannot be pollinated by natural effects. In the traditional primitive pollination method an entire male spathe is placed in the crown of the female palm and wind will do the pollination but this leads to a great loss of pollen. Artificial pollination results in good fertilisation with a reduced number of male palms with male/female ratio of 1/50. Artificial pollination could be realised by using a mechanical device (Enaimi and Jafar, 1980). One of the following techniques could be used in artificial pollination;

Fresh male strands: two or three freshly opened male spathe are placed in a longitudinally inverted position, between the inflorescence strands of the female.

Pollen suspension: where a pollen grain suspension is sprayd into the tree. The suspension contains 10% sucrose and 20 ppm GA3− agar.

Dried pollen: dry pollen to be dusted on cotton puffs and placed between the strands of female inflorescences.

Mechanical pollination: using a ground-level duster or aircraft pollination. The advantages of mechanical pollination includes; labour and pollination time reduction. In mechanical pollination good fertilization can be achieved by mixing pollen from different sources.

2.6. Fruit thinning

Fruit thinning process will lead to a regularity in dates production from year to year. It will improve the fruit size and fruit quality and texture. The thinning to be carried out at three levels:

(i) reducing the number of bunches per palm to keep a proper balance between the number of leaves and fruit bunches.
(ii) reducing the number of strands per bunch removing 50–60% of the flowers or fruits on the bunch.
(iii) reducing the number of fruits per strand. The final amount of dates per strand (20–35) and the number of strands per bunch (30–50), and producing on the average 7–11 kg of fruit per bunch.

2.7. Additional processes

Additional cultivation processes on the palm tree includes; bunch lowering and support, bunch covers, to protect fruits from high humidity and rain, from bird attacks and insects. Leaf pruning, which is the removal of dead, or nearly dead fronds and their bases.

Dethorning is the removal of spinesor thorns. This is done to facilitate pollination and fruit bunches handling and more imporantly to avoid accidents and thorning of workers during the various tree processes. Pest and disease control using specific pesticides as needed.

Fig. 2 shows the flow of pre-harvesting cultivation process for date palm tree indicating all necessary inputs to execute every process.

2.8. Date harvesting

Dates could be harvested and marketed in three different fruit forms. The first form is called Khalal which is yellow, hard and crisp and has a moisture of 50–85%. The second form is called Rutab which is partially brown, more softened and with a moisture content of 30–40%. The third form is the Tamar which has a dark brown color with a soft pliable texture and a moisture content of 25% (Abdelouahhab, 2002).

Harvesting the fruit requires reaching to the fruits by

experienced workers, or climbing aluminium ladders, or employing mechanical lifts for workers to climp up the palm tree. The harvested fruit is filled in containers for transport to the packing and treatment station to prepare for market or for storage.

2.9. Treatment – packaging-storage

After dates harvesting fruits are transported to the treatment and packaging facilities. Treatment processess include fumigation, washing, hydration, dehydration, sorting, packaging and storage or transport to the market. Fig. 3 shows flow chart of these processess. Above processes are explained breifly below.

Fumigation: process aims to clean fruit completely from any pests, including the eggs, the pupas, the larva or the adults, in order to be stored for a year or more. Methyl bromide (CH_3Br) is usually used for cleaning (fumigation) to force insects to leave the fruit to be killed then by gas. Phosphine is widely used in developing countries as well as using atmospheres high in carbon dioxide. Other methods invovle active oxygen (ozone, hydrogen peroxide) and irradiation (Abdelouahhab, 2002).

Washing: Date fruits are washed thoroughly using clean water before storage.

Hydration and dehydration: After washing by water, date fruits are hydrated or dehydrated before storage to providethem with a uniform moisture content of 10–20% which leads to the extension of the storage and marketing period.

Hydration process is done by saturating the texture of the date fruit with water or steam to enrich moisture under appropriate temperature, this softens the fruit by creating optimal conditions for enzymatic activity. When the moisture of fruits reaches a level higher (above 20%), dehydration is done. Dehydration is undertaken by exposing fruits to a controlled hot air flow in special chambers.

Sorting; along with the sorting the damaged and unqualified fruits are removed manually. Such process is mostly done by human, however this process can be carried out by automatic grading using machines more efficiently. The qualified fruits are sorted according to their size or weight as (jumbo, large and medium).

Storage and refrigeration: Quality of fruits must not be influenced by storage, texture, moisture and color should be kept unchanged during refrigeration and storage process, this can be done by preserving dates for a long time under low temperature that reached to −18 °C

After harvesting dates they either go to packaging or to processing. Most of the produced dates are packaged directly to be used as fresh fruits without any cooking or processing. Processed dates can be used in beverage in the shape of date coffee or molasse (Dibs). For processed food it can be extracted in the shape of paste (Ajwa) to be used in traditional sweets (Assi, 2018).

3. Sustainable model of date palms

For Palestine with very limited resources and peculiarly political situation, development needs to be sustainable. Palm tree is a growing and promising sector with potential of export of its products. However palm tree requires the use of large amounts of precious water for irrigation and the employment of mostly skill labor for cultivation and harvesting of the fruits.

The date palm sector needs to be improved significantly to increase its contribution in the Palestinian economy. On the other hand, farmers and investors should keep an eye on the sustainability of the sector making sure of the positive influence of the different cultivation processes on the sustainability pillars: economic, social and environmental.

Fig. 4 depicts a sustainability model for the date palm cultivation using the Welsh Doughnut modelling technique. Doughnut model represents the different inputs of the system that are: irrigation, energy, labour, machinery, fertilizers and pesticides. Land & soil are not included in our analysis as it exists and will be reused many times similar to the air and sun radiation. In the doughnut model, moving the input radially inwards towards the center means increasing its use that leads to increase the profit and added value of the production while reducing the sustainability. Moving radially outwards away from the center means decreasing the use of pillar leading to decrease the profit and added value of the production, while increasing the sustainability of the sector (Sayers, 2015).

Looking at the irrigation process in Fig. 4, one sees that due to the high quantity of water needed for irrigation there is a big influence on the existing water resources, both on surface and underground. Most of the farmers use flooding technique in irrigation, which causes high evaporation rate since most of the date palm farms exist in the desert and hot areas. This problem can be solved by using efficient drip irrigation technique and undersurface irrigation to avoid high quantities of evaporation. Evaporation is significantly high with temperature in Jordan Valley reaching 45 °C in summer.

Energy consumption is another important variable that has high impact on environment, energy is required here in the shape of electrical energy to operate the pumps needed for irrigation from one side and in the shape of fossil fuel to energize the vehicles used for pollination, cultivation and harvest processes. The suggested solution for energy is using solar energy that exists intensively in Palestine most of the year. Solar energy can be used in stationary applications like irrigation and post-harvest packaging. To that end, solar energy such as photovoltaic and Gemasolar technologies can be used to provide energy to drive the cultivation machines and tools.

Labor is the main aspect that has high impact on the society, improving the social pillar of sustainability. It is a positive point to increase the number of employed workers in the date palm sector. At the same time, it is necessary to initiate qualification-training programs to turn them to skilled labor. This in turn increases the productivity and improves the social and economic level of the workers. On the other hand, machinery and equipment are

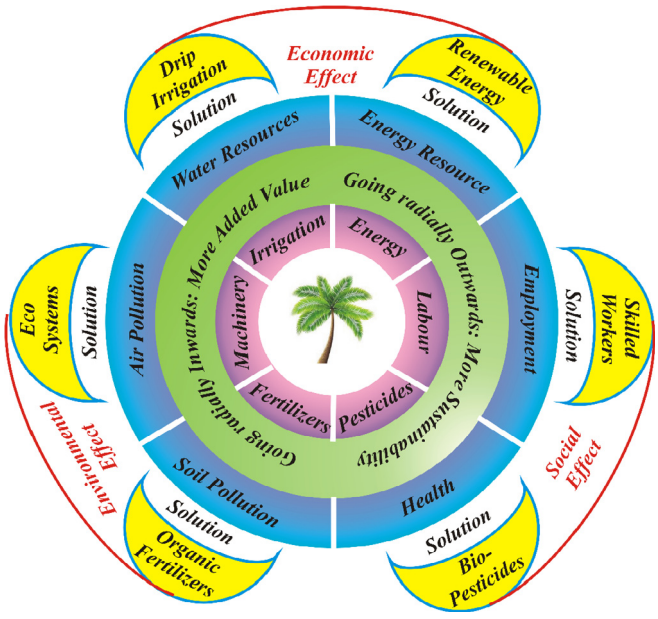

Fig. 4. Sustainability doughnut model for date palm cultivation.

necessary to be used in pollination, thinning, pruning, treatment, and harvesting processes of dates. Most of these machines are driven by fossil fuel and contribute in the CO_2 emissions polluting the air. The suggested solution here is to obey the international eco systems for these machines to reduce polluting emissions. Moreover, as suggested before to use solar systems that produce CO_2 emission-free electricity to empower electric vehicles and equipment employed in previous cultivation processes.

Fertilizers are required to improve the palm tree productivity; chemical fertilizers are mostly used in the sector leading to soil and underground water pollution. The best solution here is to use organic fertilizers such as animal manure that has no bad influence on environment. Red weevil and other pests have a devastating influence on the palm trees by damaging the trunk and crown of the tree. Farmers use chemical pesticides to fight this problem, these chemical pesticides are extremely dangerous to the human health of the workers and even to the end users consuming the fruits. Suggested solution for this problem is to use bio-pesticides made of natural components or semi chemical mediated strategies including "attract-and-kill" or "attract-and-infect" methods for eco-friendly management of these pests [4] (Ali-Shtayeh and Jamous, 2002; Abu Daqqa, 2019).

4. Added value and feasibility study

Regardless of the sustainability issues, the date palm cultivation sector from the economic side is a feasible business and deserves to be improved. Table 4 lists some economic indicators over the age of the palm tree (Takele et al., 2006). According to agricultural estimations, farmers can plant 33 palm trees in one dunum (or 330 palm trees in 1 ha), however in this table the values are given per palm tree. The first column shows the produced dates in kg per palm tree per year. The values from the 10th to the 50th year are taken as an average value for each range for simplicity of reading the table.

For better presentation and subsequent discussions, the numerical values are illustrated in Figs. 5 and 6. Fig. 5 represents the annual quantity of production of one palm tree showing the variation of produced dates in kg over the years of its age. It is clear that the palm tree starts producing dates after the 4th or 5th year of its age with small yearly quantities increasing gradually till reaching its mature age at 8–10 years old. In the period from the 10th to the 35th year it produces its maximum capacity that reaches up to 125 kg/year specially for the Madgoul which is considered as one of the best types. After the 35th year, production starts to decrease sharply losing its feasibility. Literature authors (Baloch et al., 2014)

Table 4
Production (taken from (Takele et al., 2006)), cost, revenue and added value per date palm tree.

Year	Production (kg)	Cost (USD)	Revenue (USD)	Added Value (USD)
0	0	20	0	−20
1	0	100	0	−100
2	0	140	0	−140
3	0	190	0	−190
4	15	230	91	−139
5	35	280	213	−67
6	45	330	274	−56
7	60	375	366	−9
8	80	440	488	48
9	110	500	671	171
10–35	125	554	762	208
35–40	110	554	732	178
40–45	80	554	488	−66
45–50	40	554	244	−310

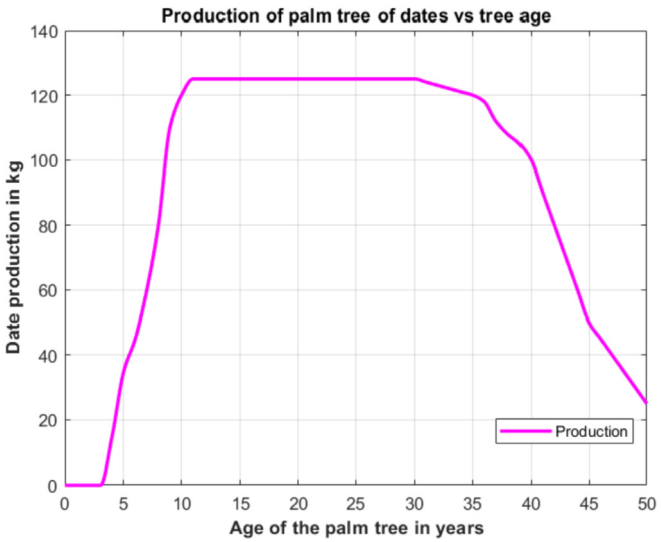

Fig. 5. Production of date palm tree in kg per year.

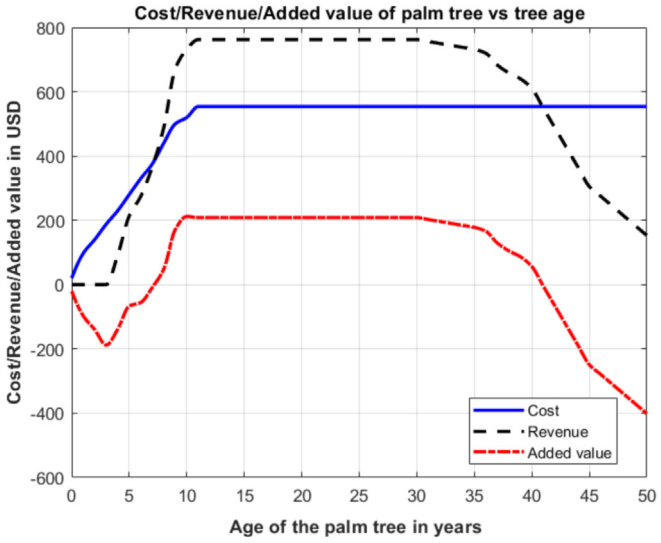

Fig. 6. Cost, revenue and added value of date palm tree in USD per year.

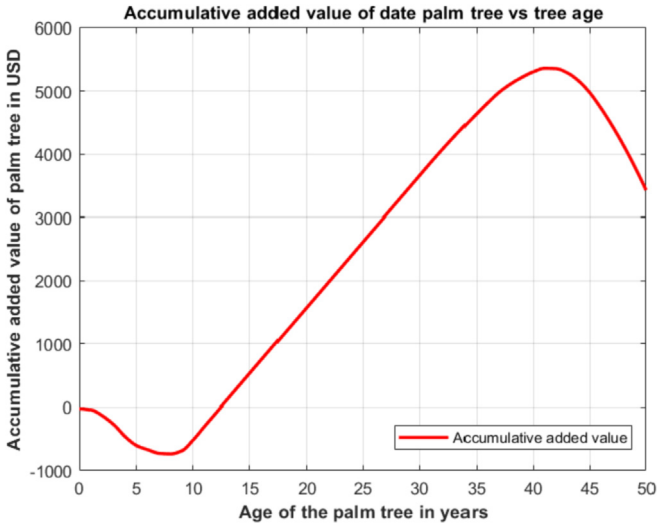

Fig. 7. Accumulative added value of date palm tree.

claim that 35 years is the maximum age of the date palm tree, where the tree should be cut and removed, but our study of the accumulative added value presented in Fig. 7 shows that it would be feasible to keep the tree till the 41st year of its life despite the decay in its production.

Fig. 6 includes three curves: the cost, the revenues, and the added value. The costs are calculated using equation (1) by summing the six input items:

$$Cost = Irrigation + Energy + Labour + Machinery + Fertilizers + Pesticides \quad (1)$$

The irrigation consumption reaches 120–140 m^3 of water per tree per year which costs more than USD 200. The machinery includes using equipment for land ploughing, harvesting, and operation and maintenance. Looking at the cost curve (Solid blue curve in Fig. 6), one can see that the costs of growing up a palm tree increases gradually till reaching its maximum level (USD 554) at the 10th year and then it levels constant for the rest of the tree's life. The tree reaches a height after which it can be reached only by using special machinery and other costs will be constant throughout the rest of its life.

The revenues (Dashed black curve in Fig. 6) of one palm tree depend on the production of that tree. Knowing that the average price of 1 kg of dates is sold at USD 6.1, the annual revenues per tree are estimated by multiplying the quantity of production in kg by the price in USD, values are taking from Table 4:

$$Revenues = Production \times Price \quad (2)$$

The revenues in equation (2) start after the 4th year where the tree starts production and keeps increasing till the 10th year where it reaches USD 762 and stays constant till the 35th year of the tree's age (maturity period) after which it starts to decay and roll off.

At the same scale, in Fig. 6, the added value of one tree can be seen in (Dotted red curve). The added value, or the annual profit, is simply the difference between the revenues and costs of one tree per year as $ per year per tree:

$$Added\ Value = Revenues - Costs \quad (3)$$

It is clear that the added value calculated by equation (3) is negative during the first 7 years which means that there is a deficit during this period after which the tree starts to give its profit that reaches its maximum value of (USD 208) after the 10th year, but this starts to roll off after the 35th year as well.

The added value calculated in Fig. 6 gives an indication about the annual profit per tree. In order to have an overview on the whole profit, the accumulative added value or lifetime profits are calculated and presented in Fig. 7. The accumulative added value in equation (4) is calculated by summing the profit of the specific year (i+1) to the sum of profits (negative and positive) of the previous years (i):

$$Accumulative\ (i+1) = Accumulative(i) + Added\ value\ (i+1) \quad (4)$$

There are two main lessons can be learned from the accumulative added value curve in Fig. 7. The first lesson is that the curve stays negative (deficit) till crossing the x-axis at the 12th year, which means that this is the breakeven point at which the payback of the tree occurs after 12 years of its age. The second lesson is that the maximum accumulative profit (added value) equals to USD 5360 per tree is obtained at the 41st year of its life. The second point implies that on the contrary of the known fact, it is better to keep the tree for a period of 41 years instead of 35 years before cutting it out, because it gives more accumulative profit per tree.

5. Conclusions and future work

This paper discussed the recent situation of the date palm cultivation sector in Palestine. After investigating the background and problems facing this sector in Palestine, the authors established an IDEF block diagram representing the lifecycle and supply chain of the date palm. The block diagram shows the necessary inputs for the cultivation process and the outputs produced from the tree. Many types of dates are produced in Palestine to cover the needs of the local market and exports. A sustainability doughnut model has been developed for the sector emphasizing on the best practices and solutions necessary to keep the sector sustainable with respect to economic, environmental, and social aspects. Thus increasing the productivity and profit on one hand and reducing consumption of water and the risk to the workers on the other hand. A few solutions have been proposed to conserve the consumption of water and energy, some of which depend on using renewable and sustainable resources specially using solar power knowing that Palestine is very rich in solar power. Labour employment and health need to be enhanced by holding training programs for the workers. Pollution is another problem caused by fertilizers and insecticides that pollute soil and the air, this also can be solved by using organic materials. The costs, revenues and added value for one tree per year are calculated showing the feasibility of growing date palm trees and the optimum age of these trees. An additional contribution of the paper is the estimation of accumulative added value through which it was found that the payback period of a palm tree is around 12 years, and the other finding is that the end of life for palm tree is 41 years after which it becomes unprofitable. Irrigation techniques, using solar energy for irrigation, dealing with waste streams, besides other problems can be tackled in future work to develop and enhance the date palm sector and increase its feasibility in Palestine.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Ahmed Abu Hanieh: Conceptualization, Methodology, Supervision, Software.

References

Abdelouahhab, Zaid (Ed.), 2002. Date Palm Cultivation, FAO Plant Production and Protection, Paper 156, Rev. 1. FAO, Rome.
Abed Rabou, Abdel Fattah, Radwan, Eqbal, 2018. The state of the date palm (Phoenix dactylifera) in the Gaza strip, Palestine: a questionnaire-based study. IUG J. Nat. Stud. 26 (2), 27–37, 2018.
Abu Daqqa, Mashhour, July 2019. Economics of Palm Cultivation in Palestine. Report submitted to Birzeit University.
Abu-Qaoud, H., 2015. Date palm status and perspective in Palestine. In: Al-Khayri, J.M., Jain, S.M., Johnson, D.V. (Eds.), Date Palm Genetic Resources and Utilization. Afr Amer, vol. 2, pp. 423–439.
Al-Oqla, Faris, Sapuan, S.M., 2014. Natural fiber reinforced polymer composites in industrial applications: feasibility of date palm fibers for sustainable automotive industry. J. Clean. Prod. 66, 347–354.
Ali-Shtayeh, M., Jamous, R.M., 2002. Red list of threatened plants" of the West Bank and Gaza Strip and the role of botanic gardens in their conservation. In: Biodiversity and Environmental Sciences Studies Series No. (2), Biodiversity and Environmental Research Center (BERC). Biodiversity & Biotechnology Research Unit (BBRU), Til, Nablus, Palestine.
Assi, Mohammed, June 2018. Date Palm (Phoenix Dactylifera) Cultivation in

Palestine, Seminar 2, Master of Sustainable Engineering in Production. Birzeit University.
Baloch, Jahangeer, Baloch, Sana Ullah, Baloch, Shahbaz Khan, Bashir, Waseem, Baloch, Hafeez Noor, Sabiel, Salih IL., Ahmed Badini, Shabeer, Dad, Rahim, 2014. Economics of date palm (Phoenix dactylifera L.) production and its development in district kech, balochistan Province of Pakistan. J. Econ. Sustain. Dev. 5 (22).
Bulushi, Karima Al, Attard, Thomas M., North, Michael, Andrew, J., Hunt, 2018. Optimisation and economic evaluation of the supercritical carbon dioxide extraction of waxes from waste date palm (Phoenix dactylifera) leaves. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2018.03.117. Accepted on 11 March 2018.
El-Juhany, Loutfy, 2010. Degradation of date palm trees and date production in Arab countries: causes and potential rehabilitation. Master Thesis, the Islamic University of Gaza, Palestine. Aust. J. Basic Appl. Sci. 4 (8), 3998–4010.
Enaimi, J.H., Jafar, A., 1980. La physiologie et la morphologie du palmier dattier (Phoenix dactylifera L.). Université El Basra, Iraq, p. 257.
FAO [Food and Agriculture Organization], 2013. Food and Agriculture Organization Statistical Database (FAOSTAT). Retrieved from. http://faostat3.fao.org/. at 23/6/2015. On 19/8/2019.
Fayyadh, J.M., Al-Showiman, S.S., 1990. Chemical composition of date palm (Phoenic Dactylifera L.), Jour. Chem. Soc. Park 12, 1.
Forum for sustainable palm oil. https://www.forumpalmoel.org/Array retrieved on 20/8/2019.
Guesmi, Ahlem, Dhahri, Hajra, Ben Hamadi, Naoufel, 2016. A new approach for studying the dyeability of a multifibers fabric with date pits powders: a specific interest to proteinic fibers. J. Clean. Prod. 133 (1 October 2016), 1–4.
Keser, Mesut, 2017. Development and expansion of sustainable date palm production systems. https://www.icarda.org/media/news/ published on October 22, 2017.
Lemlem, Aregawi, Alemayehu, Melkamu, Endris, Mossa, February, 2018. Date palm production practices and constraints in the value chain in Afar regional state, Ethiopia. Adv. Agric. 2018 https://doi.org/10.1155/2018/6469104. Article ID 6469104.
Nulken, Markus, Nulken, Daniel, Marnet, Rodulf, 2015. Nulken sustainability report 2014 – 2015. https://www.noelken.de/fileadmin/img/PDF/Nachhaltigkeitsbericht_2015_ENG.pdf retrieved 19/8/2019.
Proposal from the United Arab Emirates for the Designation under the GIAHS Program of Al Ain and Liwa Historical Date Palm Oases. Draft 7 January, 2015.
RSPO, 2019. Roundtable on Sustainable Palm Oil. https://www.rspo.org/about. retrieved on 19/8/2019.
Sait, Hani, Ahmad, Hussein, Arshad, Adham Salama, Farid Naser, Ani, August 2012. Pyrolysis and combustion kinetics of date palm biomass using thermogravimetric analysis. Bioresour. Technol. 118, 382–389.
Sayers, Malcolm, The Welsh Doughnut, March 2015. A Framework for Environmental Sustainability and Social Justice, Oxfam Research Report.
Silitonga, A.S., Masjuki, H.H., Ong, Hwai Chyuan, Kusumo, F., Mahlia, T.M.I., Bahar, A.H., July, 2016. Pilot-scale production and the physicochemical properties of palm and *Calophyllum inophyllum* biodiesels and their blends. J. Clean. Prod. 126 (10 July 2016), 654–666.
Takele, Etaferahu, Mauk, Peggy, Sharabeen, Ihab, 2006. Sample Costs to Establish a Date Palm Orchard and Produce Dates in Coachella Valley Riverside Country, 2005 – 2006. University of California (UCCE).
UNEP, 2003. Desk Study on the Environment in the Occupied Palestinian Territories. United Nations Environment Program (UNEP), p. 188.